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INFLUENCE OF HYPOXIA ON COLOR VISION

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(Presented by K. M. Bykov, Member of the Academy,
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There are many papers dealing with research on the influence of hypoxia on different visual functions. In particular, the effect of oxygen starvation on color discrimination has been studied in the Soviet Union by N.A. Vishnevski and B.A. Gyrilin [1], by N.G. Fedorov and V.I. Fedorova [2], by B.N. Aronova [3], and more recently by L.M. Mkrtycheva and V.G. Samsonova [4] and others.

Vishnevski and Gyrilin's results, formulated as "relative color sensitivity", are highly consistent for all forms of signal studied, and reveal a maximum "high-altitude" sensitivity depression factor of two or three as compared with normal ground conditions. N.G. Fedorov and V.I. Fedorova [2] employed various means of studying high altitude color vision over a considerable period of time during an ascent of Mt. Elbrus. They found no manifestations of color-blindness up to an altitude of 5300 m. At an altitude of 2200 m the Rayleigh test already showed a departure from the norm of deuteranomalous type, which gradually increased over a period of seven days to a certain maximum level, and which the authors are inclined to ascribe (even if only in part) to insolation, since they also found a similar effect at sea level in the south. B.N. Aronova [3] finds that her tests fully confirm the data of Vishnevski and Gyrilin; they reveal a general depression of color discrimination for all color-tests, as was also observed during the Elbruz climb.

Mkrtycheva and Samsonova [4] have determined saturation thresholds for color discrimination. The authors formulate their results on color discrimination as a depression of sensitivity (a rise of the discrimination threshold) for green and blue light and an augmentation of sensitivity (lowering of the thresholds) for red and yellow; this was observed in all of five subjects studied. The authors furthermore find an absence of any marked changes in the curve of relative visibility for the foveal part of the retina "under conditions of daytime vision". * However, when the experiments were made for the macular

* Exception may be taken to the authors' interpretation of their results as characterizing "the relative sensitivity of the eye to brightness". Indeed they made no determinations of the brightness-threshold in the discrimination of monochromatic fields; they compared polychromatic fields and found the closest color in terms of brightness. Moreover, if it is legitimate in the case of night vision to regard the visibility curve as an authentic index of the spectral sensitivity of the actual physiological apparatus (the rods), the matter is quite otherwise in the case of the cones, which are of three types, distinguishable by their spectral sensitivity (and characterizable first and foremost in these terms).

zone or even the extramacular zone of the retina under conditions of night vision, then in almost all the subjects studied there was observed, in one degree or another, a quite perceptible displacement of the visibility curve under the influence of oxygen starvation.

Our observations of the influence of oxygen starvation on color vision were made with the new National Optical Institute anomaloscope evolved by G.N. Rautian [5]. A feature of the new instrument is that it qualitatively characterizes, on the basis of threshold procedure, the separate functioning of each of the three systems of retinal color-sensing receptors (cones). In each of three tests, one establishes the incidence of threshold color discrimination for ocular half-fields (of 6° angular size); this incidence is made perceptible to the subject by varying the stimulation of one particular system of cones (the system under investigation), while meanwhile the stimulation of the two other systems remains unchanged, the same as at the initial moment when the half-fields were precisely identical. Along with this the instrument (in a fourth test) also characterizes the typicalness of or the anomalous deviations in the spectral sensitivity of the receptors, in the same way as, for instance, the Nagel anomaloscope.

The tests were conducted in a low-pressure chamber. For every subject we determined all three threshold indices n_R , n_G , n_B [3] at normal pressure, that is, the "ground" indices. Then the "ascent" was initiated in the low-pressure chamber, and further determinations of the n -indices were made at a succession of increasing "altitudes". At the "ceiling altitude" (5000-7000 m) the observations were made both under conditions of oxygen insufficiency and with oxygen supplied. Threshold determinations were also made during the "descent" and, finally, after return to normal conditions.

The analysis of the test data consisted in calculating the subject's thresholds, expressed as ratios to his normal "ground" thresholds:

$$n/n_0 = v$$

In each of the graphs here reproduced, the values of the coefficient, plotted as ordinate in the downward direction, give a picture of the changes in the acuity of color discrimination under the influence of hypoxia for each receptor system.

In all we tested twenty-five persons possessing normal color vision, with whom we conducted thirty "ascents". The mean data secured in "ascents" up to 5000 m are given in Figure 1, and show a decrease in the acuity of color discrimination for all three receptor systems, although in different degrees. The greatest depression of color discrimination (by a factor of 2) occurs in the third (blue-sensing) receptor. The first (red-sensing) receptor has its discrimination reduced by a factor of 1.7, and the second receptor by a factor of only 1.3. In Figure 1 it is also seen that inhalation of oxygen (for a period of 2 to 3 minutes) almost restores color discrimination. Here there emerges a peculiarity of the second receptor (the green-sensing receptor), namely, a sharpening of color discrimination at minor altitudes and a comparatively small reduction at high altitudes, as compared with the other two receptors. The data secured in "ascents" to 6000 m (eight subjects) and to 7000 m (four subjects) yield similar results, but with a more marked depression of discrimination than in the 5000 m ascents.

The whole experimental material may be broken down into four groups of curves: in the first group (three cases) all three receptors, at "high altitude", are depressed to the same degree, by a factor of 1.6 as compared with the "ground" data. In the second group (three cases) color discrimination is most depressed in the second type of receptor, by a factor of 2 to 3.2 as compared with the initial data, while in the first and third types of receptor the observed depression is not greater than 1.5 to 2.0. In the third group (ten cases) the greatest reduction of color discrimination acuity occurs in the first receptor; by a factor of 2 to 4 as compared with the initial "ground" data, while in the two other receptors the depression factor was, as before, only 1.5 to 2.0. The fourth group of curves includes cases (six in number) with the maximum depression of color discrimination in the third type of receptor, namely, by a factor of 1.5 to 3; while in the two other types of receptor the reduction is of the same order as before, namely 1.5 to 2.0.

In many cases the strongest depression is observed only in one particular receptor, but in a number of cases (five out of thirty) the two receptors are maximally depressed to the same degree, an effect which we must regard as a more serious deterioration of color discrimination.

Analysis of the experimental material reveals the following interesting feature. At "high altitudes" the acuity of color discrimination was more strongly affected in proportion to the degree of "ground" acuity. This was found in all cases and for every receptor, as is indicated by the mean data shown in Table 1.

TABLE 1

Color Discrimination	R Receptor		G Receptor		B Receptor	
	"Ground"	5000 m	"Ground"	5000 m	"Ground"	5000 m
Below normal *	1	1.28	1	1.03	1	1.44
Normal	1	1.83	1	1.43	1	1.98
Above normal	1	2.33	1	1.96	1	2.12

* The mean norms were established shortly before the experiments by one of the authors, on a basis of 900 subjects.

In repeated tests on the same subjects there was observed a variability in the acuity of the different receptors under "ground" conditions. In conformity with the above-indicated rule, the strongest depression (at altitude) took place in that receptor which on that particular day was found to be the most sensitive (Fig. 2, A and B).

At "low altitudes" (2000-3000 m) there was observed in most cases a sharpening of color discrimination for one or for two of the receptors. Most frequently this was the second receptor (sixteen cases); less frequently the third (fourteen cases) and still less frequently the first (ten cases). From 3500-4000 m this increased acuity was replaced by the usual depression. The receptors exhibiting the increased acuity at "low altitudes" exhibited, as a rule, the least depression at "high altitudes". A characteristic case is shown in Figure 3. Oxygen inhalation at high altitudes restores color

discrimination to all three receptors, almost to the initial level. The acuity of discrimination is restored to a lesser degree in those receptors which were most depressed (Fig. 3).

Our results agree with the findings of Vishnevski and Gyrlin, with those of Fedorov and Fedorova, and with those of Aronova, but do not support the conclusions of Mkrttycheva and Samsonova as to reciprocal variation, under hypoxia, of the thresholds for red-yellow and for green-blue.

In addition to determining the color discrimination thresholds, we carried out tests on the behavior of the Rayleigh equation. In none of the five cases did we discover any noticeable changes in the equation with altitude. The same thing is found by other authors for brief hypoxias. The variations which were found by Fedorov and Fedorova are, it would seem, the result of oxygen starvation of many days' duration, and are possibly due to insolation too. Recently Ye. N. Yustova [6] has shown that anomalous changes in the Rayleigh equation must be ascribed to the properties of the retinal pigmentation. It is natural to believe that this chemical effect will not show up in experiments of short duration.

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* We note here that the colors red, yellow, green and blue are not equivalent to excitations of any single one of the receptors.

Relative units

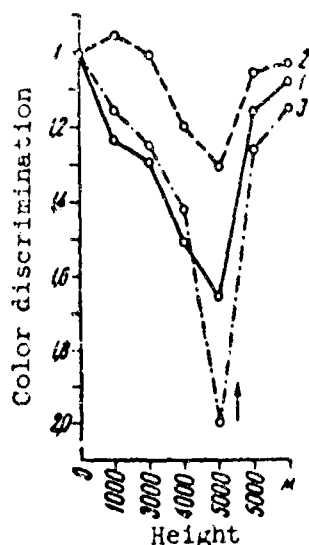


Fig. 1. Variation of color discrimination during hypoxia. The graph is plotted for mean data. 1 - red, 2 - green, 3 - blue. The arrow indicates administration of oxygen.

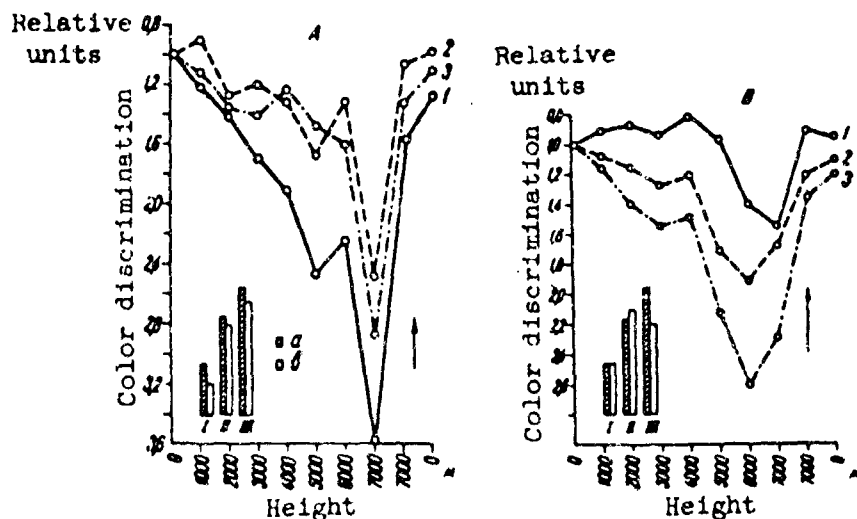


Fig. 2. Different variations of color discrimination in the same subject, as related to different initial functional states of the visual analyser.

A - subject D.; experiment of June 13, 1953.

B - subject D.; experiment of June 15, 1953.

a - mean norms of color discrimination at "ground altitude", for receptor groups I, II and III.

b - this subject's color discrimination at "ground altitude", before the "ascent".

1 - red receptor, 2 - green, 3 - blue.

The arrow indicates administration of oxygen.

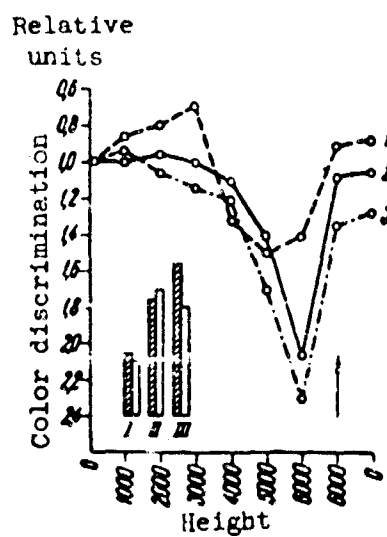


Fig. 3. Example showing depression of color discrimination at high altitude to be smallest for that receptor which had greatest low-altitude acuity. Subject A., experiment of May 19, 1953. Notation same as in Figure 2.